Generalized Operations Simulation Environment For Aircraft Maintenance Training

Terence S. Andre, Lt. Col, PhD
Winston R. Bennett Jr., PhD
Anna R. Castillo, MS
Dale P. McClain, AOS
Mathew D. Purtee, Lt
Brenda M. Wenzel, PhD
Warfighter Training Research Division
Air Force Research Laboratory
6030 South Kent Street
Mesa, Arizona 85212-6061

Mary Graci, MEd
Maricopa Institute for Virtual Reality Technologies
Chandler-Gilbert Community College
7360 East Tahoe Avenue
Mesa, Arizona 85212

Summary

A training need exits for a common, cost-effective virtual reality simulation platform for aircraft maintenance training. The need is driven by a lack of concurrency between equipment and simulators, inaccessibility of equipment and simulators for training, high life-cycle and sustainment costs for training simulators, and the absence of full-scale assets or mock-up devices at training squadrons. In the absence of training assets and devices, resident training has been restricted to traditional methods such as referencing technical orders and academic courseware. An additional need for on-demand training at operational units has contributed to increased costs by allowing maintainers to use operational flight simulators that often require declassification for maintenance training purposes. This paper describes the assessment of the Virtual Environment Safe-for-maintenance Trainer and development of the Generalized Operations Simulation Environment, the next generation virtual reality aircraft maintenance training program.

1 Introduction

The Virtual Environment Safe-for-Maintenance Trainer

The Virtual Environment Safe-for-Maintenance Trainer (VEST) was developed in 1997 as a cooperative effort among the 363rd Training Squadron (TRS), Sheppard Air Force Base (AFB), Texas, the Air Force Research Laboratory (AFRL) through a contract with Command Technologies Incorporated (CTI) at Brooks Air Force Base, Texas, and the Air Education and Training Command (AETC), Randolph AFB, Texas. The trainer was designed to meet three basic needs: (a) train switchology for F-15E-model two seat cockpits, (b) train F-15E-model weapons stations familiarization, and (c) train specific ground safe-for-maintenance tasks on the F-15E model. Full-scale F-15E model aircraft are not available, as training assets, at the 363rd TRS.

VEST is an immersive virtual reality (VR) environment that provides apprentice technicians demonstrations, drills, and checks on performance maintaining the F-15E model aircraft. The value of VEST is its low-cost replacement of the actual aircraft, thus, providing apprentices with training opportunities they would not otherwise have prior to deployment. VEST provides apprentices with contextualized, three-dimensional, interactive experiences with the F-15E model front and rear crew stations, weapons stations, and ground safe-for-maintenance. Apprentices assigned to bases with F15-E model aircraft are required to complete 21 lessons in VEST, after successfully completing baseline training on the F-15C model aircraft.

Paper presented at the RTO HFM Symposium on "Advanced Technologies for Military Training", held in Genoa, Italy, 13 – 15 October 2003, and published in RTO-MP-HFM-101.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **00 APR 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Generalized Operations Simulation Environment For Aircraft Maintenance Training**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Warfighter Training Research Division Air Force Research Laboratory 6030 South Kent Street Mesa, Arizona 85212-6061; Maricopa Institute for Virtual Reality Technologies Chandler-Gilbert Community College 7360 East Tahoe Avenue Mesa, Arizona 85212**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001667, NATO RTO-MP-HFM-101 Advanced Technologies for Military Training (Technologies avancées pour lentraînement militaire)., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

There are two VEST stations in operation at the 363rd TRS. Apprentices are seated and interact within the virtual environment through a head mounted display (HMD) and cabled joystick (see Figure 1). It takes approximately two and one half hours to complete VEST. Apprentices are given two attempts to achieve a minimum score of 70% to pass a performance check.

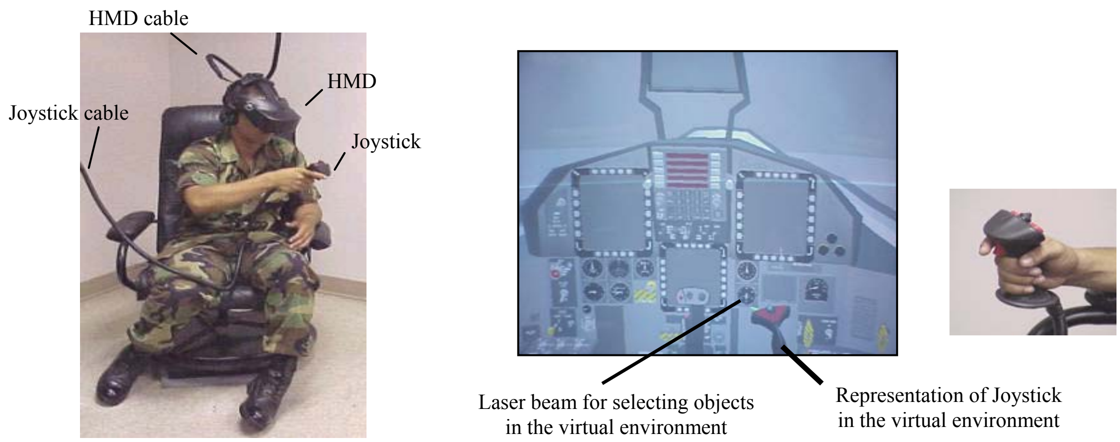

Figure 1. VEST system in operation

The Generalized Operations Simulation Environment

The Generalized Operations Simulation Environment (GOSE) project is a collaborative effort between AETC and AFRL to develop common, cost-effective, generalized VR training platforms for aircraft maintenance training, undergraduate pilot training, and space and missile training. Our initial focus is the aircraft maintenance training domain since it provided an opportunity to build on the VEST architecture. Development of GOSE involves re-engineering VEST as a scalable, modular, immersive VR training system comprised of PC-based hardware and software. GOSE initiatives include: (a) formalize training needs across airframes, (b) design instruction to meet common training objectives, (c) create a common training platform that supports multiple weapon systems, (d) increase personnel and equipment safety; (e) increase readiness in technicians trained without direct hands-on experience, and (f) reduce training costs using "virtual" replacements of aircraft assets and lower life-cycle and sustainment costs of VR platforms.

2 Evaluation of VEST

The 363rd TRS is continually assessing the current VEST system. Results from the assessment of VEST have helped us identify needed improvements to the GOSE architecture. The ongoing assessment of VEST encompasses apprentice performance scores in the VR environment and their reactions to the training experience. Apprentice technicians are asked to provide comments about their experience, strengths and weaknesses of the system, and any adverse physical effects encountered.

Performance data and comments collected from 84 apprentices assigned to complete VEST are reported here. Two apprentices were unable to complete VEST and their data was excluded from the analyses. The average performance scores across the VEST drills by number of trials is depicted in Table 1. The system failed to capture "aircraft safe-for-maintenance drill" scores for three apprentices so their overall performance scores could not be computed. The overall average performance score was 80.3%. Six of the 82 apprentices had overall average scores below 70%. Performance results indicated apprentices had the greatest difficulty with the "left console aft cockpit switch drill." Even after the maximum number of trials (two) only seven

apprentices were able to pass with acceptable scores (100%). "Review aft cockpit drill" and "weapons station drill" also indicated some degree of difficulty for 19 and 56 of the 82 apprentices, respectively. After two tries these apprentices scored only slightly over the 70% pass rate. Practice had the largest impact on the "aircraft safe-for-maintenance drill" where those who required a second try at attaining a passing score outscored those who passed on a single try ($\underline{t}_{(75)} = 3.34$; $\underline{p}$value = .001).

Table 1. Average performance of scores on VEST drills by number of tries (n=number of apprentices)

	Number of Tries			Number of Tries	
Drill	**1**	**2**	**Drill**	**1**	**2**
Left console forward cockpit switch drill	81.6 (n=53)	81.1 (n=29)	Left console aft cockpit switch drill	–	25.6 (n=82)
Main console forward cockpit switch drill	82.0 (n=59)	82.1 (n=23)	Main console aft cockpit switch drill	91.4 (n=77)	90.0 (n=5)
Right console forward cockpit	90.0 (n=77)	82.6 (n=5)	Right console aft cockpit switch drill	84.4 (n=73)	81.2 (n=9)
Review aft cockpit	84.4 (n=63)	74.2 (n=19)			
Weapons station drill	99.9 (n=26)	77.7 (n=56)	Safety device drill	87.1 (n=73)	89.0 (n=9)
Aircraft safe-for-maintenance intro drill	91.6 (n=79)	95.5 (n=2)	Aircraft safe-for-maintenance drill	76.4 (n=22)	84.8 (n=55)

Apprentice comments were assigned a category and a valance (positive, negative, or neutral) by two raters. Fourteen coding categories were used that encompassed all 263 comments (Table 2). Cohen's index "kappa" was used to derive inter-rater reliabilities, which were .95 for category assignment and .90 for valance assignment. Raters came to an agreement on divergent category and valance assignments, after making initial ratings, before computing the number of comments within categories.

Table 2. Category Definitions

Category	Definition
Aircraft:	comparison between VEST and F-15E
Content:	reference to instructional material
Experience:	reaction to VEST
Fix:	suggestion to improve VEST
HMD:	reference to VR HMD
Learn:	testimony to learning something
Learning Style:	preference for an instructional method
Media:	reference to training tool
Physiology:	physical reaction to VEST
Pointer:	reference to interface (hardware/software) for object selection

Unreliability:	reference to system glitches
Usability:	reference to interactions with VEST instructional method
Visual:	reference to quality of visual experience/graphical representation of aircraft
Voice:	reference to quality of aural experience

Table 3 presents the frequencies of comments by category and valance. On average, apprentices made 3.1 comments (range 1-7). The average number of positive comments was 1.3 (range 0-4). The average number of negative comments was 1.4 (range 0-5). The average number of neutral comments was .4 (range 0-2). The comment distributions were all positively skewed, showing fewer people made increasing numbers of comments. Categories are divided in the table between mostly positive, mostly neutral, and mostly negative comments. Overall, 41.5% of comments were positive, 13.3% were neutral, and 45.2% were negative. The division of comment categories by valance reveals 107 positive comments distributed over 5 distinct categories and 106 negative comments distributed over 8 distinct categories. All comments (23) in the "Fix" category, except one, were assigned a neutral valance table.

Table 3. Number of Apprentice Comments by Category and Valance

Mostly Positive				**Mostly Negative**			
Category	**Positive**	**Negative**	**Neutral**	**Category**	**Positive**	**Negative**	**Neutral**
Experience	39	8	8	HMD	—	5	—
Learn	37	—	1	Learning Style	—	12	1
Media	18	2	1	Physiology	—	20	—
Aircraft	8	—	—	Pointer	—	27	—
Constant	5	3	1	Unreliability	—	9	—
COUNT	**107**	**13**	**11**	Usability	2	21	—
Mostly Neutral				Visual	—	10	—
				Voice	—	3	—
Category	**Positive**	**Negative**	**Neutral**	**COUNT**	**2**	**106**	**1**
Fix	—	1	23				

No negative comments were made about learning or the value of gaining experience with an E-model aircraft. Example positive comments are "The VR program served its purpose very well and was extremely educating" and "gives you a realistic view of the aircraft and the loading stations." No positive comments were made about the peripheral devices, graphical representations, voice synthesis, physiology response, reliability, and learning styles.

A median split was conducted to create two groups of apprentices—those who performed at and below 50% of the class (average overall score of 80.5%) and those who performed above 50% of the class. Chi-Square tests revealed no difference in the types of comments apprentices made whether they performed at or above

the median score or below the median score. Nor were differences found in the number of positive and negative comments across categories based on the median split. No relationship was found between overall performance scores and number of comments made (r = .099). Apprentices were divided into three groups based on a comparison of the number of positive versus negative comments (+ > -; + = -; + < -). No significant differences were found in performance scores across the three groups [$\underline{M}_{+>-}$ = 81.3 (n = 30); $\underline{M}_{+=-}$ = 80.1 (n = 17); $\underline{M}_{+<-}$ = 79.5 (n = 32)]. (Wenzel, Castillo, & Baker 2002).

3 GOSE Development Methods and Tools

Technical specifications for VEST are presented in Table 4. A baseline configuration for VEST was completed before start of the GOSE migration. The baseline configuration included: video capture, data backup, tutorial evaluation and demonstration.

Table 4. VEST technical specifications.

	Hardware	Software
Instructor Workstation (1)	Silicon Graphics O2 Workstation 180MHZ R5000SC (secondary cache) • 128MB RAM, 4 GB Hard drive • Mouse, keyboard, monitor • 10 Base-T to BNC multi-port repeater • DAT tape SCSI Backup System • 10 DAT tapes (4mm DAT-4-8 GB)	• Network File System (NFS) • IRIX version: 6.3 operating system • C++ compiler for Irix 6.3 • VEGA™ SP Development System • Ez3D Modeler
Student Workstations (2)	Silicon Graphics Indigo2 Maximum IMPACT (Indigo2) workstation, 195HZ R10000 • 128MB RAM, 4 MB texture memory • 4 GB hard drive • 6 DOF Motion tracking device • 2 receivers with cable • 2 flock of birds electronics units • 1 flock transmitter with 10 foot cable • HMD system: Virtual Research V6 with control box • Two Flock-of-birds model 6 degrees of freedom • Cyberwand, serial version	• IRIX version: 6.2 operating system • VIVIDS 0.82b for the SGI™ • Truetalk™ Text-to-Speech engine • Vega™ 3.0 SP Runtime • Performer 2.0.4

Table 5 contains technical specifications for GOSE. GOSE is being developed as a PC-based platform enhanced with data gloves, HMD and tracking system that will provide end-users six degrees of freedom in movement. These specifications in part address issues raised in the evaluation of VEST. The enhancements are expected to improve navigation within the virtual environment (see figure 2).

Table 5. GOSE technical specifications.

	Hardware	Software
Instructor Workstation (1)	IBM Z Pro, 2 GHZ (2 processors) • 2 GB RAM, GeForce4™ video card • Mouse, keyboard, monitor	• XP operating system • Vega™ Prime
Student Workstation (1)	IBM Z Pro, 2 GHZ (2 processors) • 2 GB RAM, GeForce4™ video card • *Virtual Research V8* HMD • Two *Flock-of-birds* • Magnetic tracking system from Ascension • Pinch Gloves • Phantom™ haptic device • CrystalEyes stereographic glasses	• XP operating system • Vega™ Prime • GHOST™ software development kit

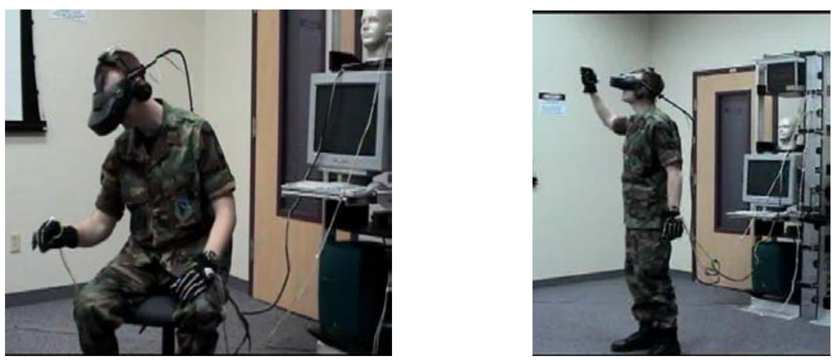

Figure 2. Concept for GOSE immersive system with improved HMD and data gloves.

Inclusion of a haptic (feedback) interface and stereoscopic glasses, along with use of three-dimensional models and synthetic voice commands, in the next phases of development should provide the end-user greater flexibility and increased realism in the immersive environment. The improvements are expected to further increase training effectiveness and reduce cybersickness. Evaluation of GOSE is planned following completion of the each phase of development. For comparative purposes, assessment criteria used to evaluate GOSE will include the same criteria used to evaluate VEST.

4 Discussion

The VEST evaluation results indicate graphical representations, joystick pointer, and cybersickness are end-user concerns. The design of GOSE is intended to address these issues and heightened usability for the end-user.

Commercial-off-the-shelf (COTS) applications to be used in GOSE accept embedded graphics (photographs), rather than constructed graphics in creating the virtual airframe. Reductions in motion lag time, making the airframe "solid," and surround detail are needed enhancements to sensory realism. It is likely that such changes in GOSE will reduce feelings of nausea and dizziness. The multimedia resource elements of VR (diagrams, images, text, video, etc.) add richness and depth to the learning experience and

can be used to facilitate strong cognitive links (Hoffman & Murray, 1999). For example, training on part replacement inside an airplane fuselage or an automobile engine can be clarified by making the virtual machine's outer layers invisible or transparent.

Peripheral devices, e.g., Pinch Gloves™ are available to allow users to interact with the virtual airframe in manners similar to how technicians interact with an actual airframe. The VEST joystick will be replaced in GOSE with data gloves to enable the experience to more closely resemble hands-on training. Apprentices will be required to reach out to interact with switches and ground maintenance safety pins. Apprentices can be seated when working in the cockpit and agile when *safe-ing* the aircraft for maintenance.

In the VEST trainer, apprentices were encouraged to take breaks every 15 to 30 minutes and not to stay in longer than 45 minutes; however, some chose to complete the exercises without breaks. Reported adverse physical reactions to the VR experience such as headache and eyestrain, may be due to the length of immersion (Gupta, Klein, & Wantland, 1996). The length of immersion may also affect the instructional effectiveness of GOSE. There are reasonable points in training content for forced breaks that would shorten immersion time and support learning. In response to end-users reactions, forced-breaks in the GOSE training are: (a) cockpit switch familiarization, (b) weapons station and safety device identification, and (c) ground safe-for-maintenance procedures.

VR adds to learning through experience. End-users learn "how to" and perform physical tasks in real-time in the virtual environment without risk to an apprentice's safety (Eline, 1998). However, instructional improvements are needed in GOSE to (a) control for information overload, (b) expand content areas, (c) extend opportunities to practice, (d) guide learning, and (e) increase accessibility to the trainer. The addition of working collaboratively in the virtual environment would further enhance the learning experience and training capability of GOSE.

5 Conclusion

Results from the VEST assessment help lead the way to GOSE, beginning with addressing realism and usability issues and guiding necessary improvements to the instructional design. GOSE will provide a VR platform to continue the research to better understand the physiological responses (e.g., headache, eyestrain, disorientation, nausea, muscle stress) to the virtual environment and to continue to explore cutting-edge methods and tools to increase training effectiveness and training transfer. Assessment of GOSE should include data to determine the extent to which training with VR systems transfers to the operational environment. Elements of the operational environment such as visual and auditory representations of the flight line incorporated in the virtual environment would likely enhance transfer of training.

6 References

Eline, L. (1998). A virtual reality check for manufacturers. American Society for Training & Development: Technical Training, 9, 10-14.

Gupta, S.C., Klein, S.A. and Wantland, C.A. Cyberpathology: Medical Concerns of Virtual Reality Applications. [online]. Available: http://www.webmed.com/mi/cyberpath.html

Hoffman H., Murray, M. (1999). Anatomic VisualizeR™: Realizing the vision of a VR based learning environment. Medicine Meets Virtual Reality, 62, 134-140.

Wenzel, B., Castillo, A., & Baker, G. (2002). Assessment of the Virtual Environment Safe-for-Maintenance Trainer (VEST). United States Air Force Research Laboratory, Technical Report Number: AFRL-HE-AZ-TP-2002-0011.

Author Biography

Terence Andre is the Warfighter Skill Development & Training Research Branch Chief at the Air Force Research Laboratory, Mesa, Arizona. He directs the Distributed Mission Training (DMT) research and development (R&D) program for the Air Force Materiel Command's premier warfighter training research branch, integrating R&D efforts with users, customers, decision makers, DoD, industry, and support contractors. Lt Col Andre manages a $10M training research budget in support of MAJCOM training needs and supervises 18 government members and 35 support contractors. He received a PhD in Industrial Engineering from Virginia Tech.

Winston Bennett is a Senior Research Psychologist with the Air Force Research Laboratory Human Effectiveness Directorate, Warfighter Training Research Division, located at Williams-Gateway Airport, Mesa AZ. He is the team leader for training systems technology and performance assessment research and development. He received his Ph.D. in Industrial Organizational Psychology from Texas A&M University. Dr. Bennett has published numerous research articles, book chapters and technical reports in the Human Resources arena. He is actively involved in research related to performance evaluation, personnel assessment, training requirements identification, and quantifying the impact of organizational interventions - such as interactive, high fidelity immersive simulation environments and job redesign/restructuring and training systems - on individual, team and organizational effectiveness.

Anna Castillo is a Research Psychologist at The Air Force Research Laboratory, Warfighter Training Research Division in Mesa, Arizona. Her research goals and objectives are to utilize a DMO environment to enhance learning and performance, and determine the extent to which lessons learned in DMO transfer to the operational unit. Anna received a Master of Science in Experimental Psychology from New Mexico Highlands University in 1998 and a Bachelor of Arts in Journalism/Mass Communications from New Mexico State University in 1995.

Mary Graci is the Director of the Maricopa Institute for Virtual Reality Technologies and Adjunct Faculty at Chandler-Gilbert Community College. Mary received her Masters Degree in Education from Northern Arizona State University and a Bachelor of Fine Arts degree in Art Education from Arizona State University. She is the pioneering spirit of the virtual reality technology program, developing education and training for college credit and corporate curricula for the largest and prestigious community college district system in North America.

Dale McClain has over 6 years experience in Graphic Design, Computer Science and Computer Animation. He has been a graphic designer, artist, animator and programmer for the Air Force and Eberly College of Business. Currently he is finishing his Bachelor of Science degree in Graphic Information Technologies at Arizona State University East. He plans to continue his education with a Masters in Science.

Mathew Purtee is a Warfighter Training Research Analyst for the Air Force Research Laboratory. His key contributions involve verbal protocol analysis and integrating virtual reality with maintenance training. He has worked as a laboratory assistant for the McSweeney Laboratory and as a student therapist for the Pacific Northwest Autism Clinic at Washington State University. Mr. Purtee earned a Bachelor of Science in Psychology from Washington State University.

Brenda Wenzel was formerly Team Lead of the Collaborative Learning Instructional Technology Team at the Warfighter Skill Development & Training Research Branch, Air Force Research Laboratory, Mesa, Arizona**.** She is currently the Senior Engineering Psychologist for the Systems Training Division, TRADOC Analysis Center, White Sands Missile Range, New Mexico. She received her PhD in Psychology from New Mexico State University, Las Cruces, New Mexico.